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IMPLEMENTATION OF PETRI NETS BASED TWO-AXIS SOLAR TRACKING SYSTEM

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ABSTRACT

An automatic two-axis sun-position tracking system for photovoltaic (PV) panel with a new designed tracking mechanism and wireless supervisory and control system was presented in this paper. The sun-position tracker mechanism was controlled by programmable logical controller (PLC). According to feedback data of encoders and signal of sensors, the PLC drives DC motors to controls elevation and orientation angles of PV panels so that the panels always maintain perpendicular to the sunlight. Petri Nets (PN) was utilized to design control algorithm of the tracking system to ensure the validity and correctness and it could be converted to ladder logic diagrams (LLD) directly, which can be executed by the PLCs, through the Token Passing Logic (TPL) methodology. As the result of the experiment, the electricity generated by the proposed tracking system has an overall improvement than the fix-angle PV system.

KEYWORDS: Two-Axis Sun-Position Tracking, Programmable Logical Controller, Petri Nets, Ladder Logic Diagrams, Solar Power

INTRODUCTION

An automatic two-axis solar tracking system with a new designed sun-position tracking mechanism and wireless supervisory and control system was implemented in this paper. The sun-position tracking system was composed of PLC-set, DC motors, worm-gears, sunlight sensing module consists of photo-sensors, rotating encoders and power relays. According to feedback data and signal of encoders and sensors, the PLC drive DC motors to adjust elevation and orientation angle of solar panel so that the PV panel can always maintain perpendicular to the sunlight. The worm-gear connected with DC motor and the strong point of them is keeping present mechanical angles of elevation and orientation without any power consumption. Sun tracker is consists of eight photo-sensors and the signal of sensors feedback to input contactor of the PLC set. Each parameter of the system, including panel voltage, elevation and orientation angle of mechanism, etc., was collected by the PLC and its A/D module, which will be transmitted to the supervisory and control program on PCs through the Zigbee wireless network.

PLC is the pivot of the proposed tracking mechanism and it can be programmed in a graphical symbolic language called Ladder Logic Diagrams (LLD) or Sequential Function Chart (SFC). Petri Nets (PN) is a very important tool to provide an integrated solution for modeling, simulation and control of in automated systems to avoid program deadlock. However, PN have not been used for the direct designs of PLC programs. This is because until the advent of Token Passing Logic (TPL) there was no any technique to convert PN into a suitable and reasonable format for implementation on the PLC. The TPL methodology bridges the gap between PN and LLD [1]-[3]. The PN was utilized to design control procedure of the tracking system to ensure the validity and correctness, and it should be converted to LLD and SFC which

can be executed by the PLCs through the TPL methodology. As a result of the experiment, the electricity generated by the proposed tracking system has an overall increase of about 19%~28% more than the fix-angle PV system in sunny days, and about 9%~13% in cloudy days.

SYSTEM DESIGNAND OPERATION

Coarse Adjustment of Mechanism

In order to track sun position effectively, the monitoring and control program should firstly calculate the theoretical elevation and orientation angles of the sun by using theoretical equations mentioned in Ref. [7] as shown in Figure 1. The PLC sent a command to drive DC motors until mechanical elevation and orientation angles of the panel were equal to the theoretical values is called coarse adjustment of the automatic tracking mechanism.

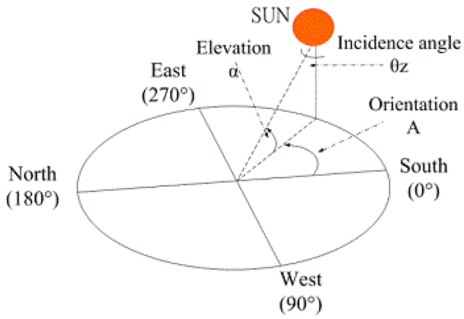
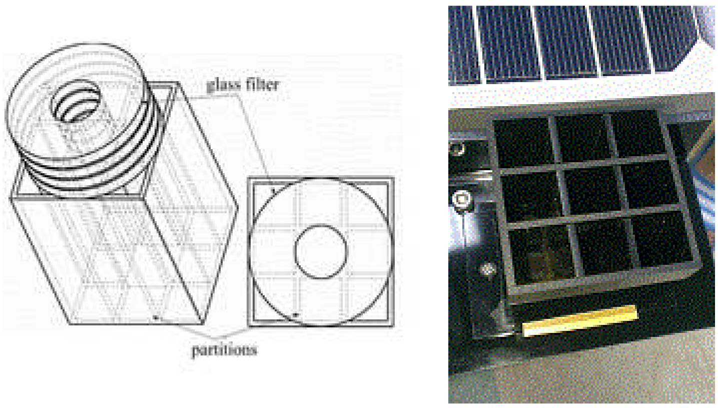


Figure 1: Illustration of Elevation and Orientation Angle of the Sun

The theoretical value of elevation and orientation angles were translated into command string for driving DC motors rotate to the corresponding position. Then, system will trim the present elevation and orientation angle of the PV panel automatically according to feedback signal of the proposed sunlight sensing module.

Fine Tuning of Mechanism

The fine tuning was proceeded every five minutes by correcting the present elevation and orientation angle of the PV panel according to feedback signal, which is comes from sunlight sensor module. Sunlight sensor module, as shown in Figure 2, is consisting of glass filters, opaque partitions and eight photo-sensors. Figure 2(b) shows sunlight sensor module is mounted aside the PV panel and it should be in the same horizon level with the panel.



(a) (b)

Figure 2: Sunlight Sensor Module (a) Blueprint; (b) Realization

Rotating Mechanism

In order to adjust elevation and orientation angle of the PV panel, there are two axis rotation should be controlled by sending command from the PLC to DC motors. DC motors do not drive PV panel directly, it was designed that rotating encoder and worm-gear are connected to DC motor sequentially. Rotating encoder feedback data to the PLC and the strong point of the worm-gear is keeping present mechanical angle of elevation and orientation without any power consumption. The cascading structure of rotating mechanism was shown in Figure 3.

Figure 3: Cascading Structure of Rotating Mechanism

PETRI NETS AND PN CONTROLLER

PN were developed by Carl Adam Petri and were based on the relationships between the components of a system, which exhibits asynchronous and concurrent activities. It is developed for describing and analyzing process information flow. PN describes problems by states with place nodes (P nodes, depicted by empty circles) and state transitions with transition nodes (T nodes, represented by horizontal or vertical bar). A set of directed arcs, which have nonnegative weights, from P nodes to T nodes or from T nodes to P nodes organized the PN. The function of P nodes is a token holder. Tokens are drawn as black dots. At any given time, the state of PN is given by the number of tokens at its places.

The PN was defined as

$\mathrm{C} = \{P, T, I, O, M, U\}$

Where

- P is a finite set of places;
- T is a finite set of transitions with $\mathrm{P} \cup \mathrm{T} \neq \emptyset$ and $\mathrm{P} \cap \mathrm{T} = \emptyset$;
- **I:** $\mathrm{P} \times \mathrm{T} \rightarrow \mathrm{C}$, is an input function matrix that defines the set of directed arcs from P to T;
- **O:** $\mathrm{P} \times \mathrm{T} \rightarrow \mathrm{C}$, is an output function matrix that defines the set of directed arcs from T to P;
- **M:** $\mathrm{P} \rightarrow \mathrm{C}$ is a marking vector whose i^{th} component represents the number of tokens in i^{th} place. The initial marking is denoted by M_0;
- **U:** $\mathrm{P} \rightarrow \mathrm{C}$ is a firing vector whose i^{th} component, u_i, represents the i^{th} transition is activated;
- An incidence matrix is defined as $\mathrm{A} = \mathrm{O} - \mathrm{I}$.

The PN control process can be induced as following equation:

$$M_d = M_0 + A \cdot \sum_{k=1}^{d} u_k$$

In proposed two-axis solar tracking mechanism, the PN control process of automatic mode and demonstrated as follows.

- **PN Control Process of Automatic Mode**

The automatic mode PN for the proposed tracking mechanism was presented in the Figure 4 with fourteen places and twenty-three transitions. Table 1 and Table 2 show definition of each place and transition, respectively.

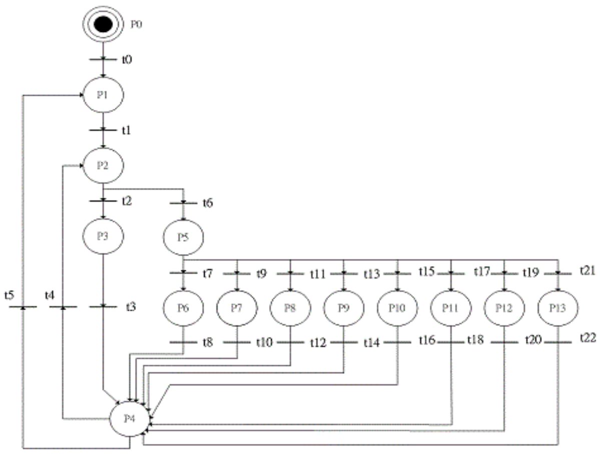


Figure 4: Petri Net for Automatic Mode

Table1: Definition of Places for Automatic Mode

Place No.	Place Status	Place No.	Place Status
P0	Enter Automatic Mode	P7	Orientation motor rotating counterclockwise for 1 sec.
P1	Execute Coarse Adjustment	P8	Elevation motor rotating clockwise for 1 sec.
P2	Execute Fine Tuning	P9	Elevation motor rotating counterclockwise for 1 sec.
P3	According to signal of sunlight sensor module to adjust rotation of orientation motor and elevation motor for every 15 min.	P10	Orientation motor and elevation motor rotating clockwise for 1 sec.
P4	Read system time.	P11	Orientation motor rotating clockwise for 1 sec., elevation motor rotating counterclockwise for 1 sec.
P5	According to signal of sunlight sensor module to adjust rotation of orientation motor and elevation motor.	P12	Orientation motor rotating counterclockwise for 1 sec., elevation motor rotating clockwise for 1 sec.
P6	Orientation motor rotating clockwise for 1 sec.	P13	Orientation motor rotating counterclockwise for 1 sec., elevation motor rotating counterclockwise for 1 sec.

Table2: Definition of Transitions for Automatic Mode

Trans. No.	Transition Status	Trans. No.	Transition Status
t0	Delay 5 sec.	t12	Elevation motor rotating clockwise for 1 sec. completed.
t1	Coarse adjustment completed, and check system time > AM 5:00?	t13	Sunlight sensor : condition 4
t2	Fine tuning completed and number of sunlight sensor is zero.	t14	Elevation motor rotating counterclockwise for 1 sec. completed.
t3	Check orientation and elevation angle of the mechanism are equal to the sun.	t15	Sunlight sensor : condition 5
t4	Check system time < PM 6:30?	t16	Orientation motor and elevation motor rotating clockwise for 1 sec. completed.
t5	Check system time >= PM 6:30?	t17	Sunlight sensor : condition 6
t6	Fine tuning completed and number of sunlight sensor is nonzero.	t18	Orientation motor rotating clockwise for 1 sec., elevation motor rotating counterclockwise for 1 sec. completed.
t7	Sunlight sensor : condition 1	t19	Sunlight sensor : condition 7
t8	Orientation motor rotating clockwise for 1 sec. completed.	t20	Orientation motor rotating counterclockwise for 1 sec., elevation motor rotating clockwise for 1 sec. completed.
t9	Sunlight sensor : condition 2	t21	Sunlight sensor : condition 8
t10	Orientation motor rotating counterclockwise for 1 sec. completed.	t22	Orientation motor rotating counterclockwise for 1 sec., elevation motor rotating counterclockwise for 1 sec. completed.
t11	Sunlight sensor : condition 3		

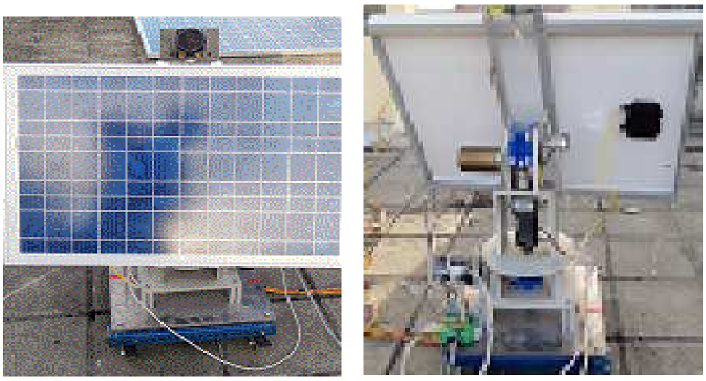
- **Transformation between PN and LLD**

PN have not been converted to PLC LLD or SFC programs directly until the advent of TPL. TPL provides a suitable and reasonable format for converting PN structure to the SFC or LLD [5]. Therefore, PN was utilized to design control logic procedure of the tracking system to ensure the validity and correctness and then, it was converted to SFC and LLD which can be transferred to the PLC’s memory, and executed on the PLC.

SYSTEM REALIZATION AND EXPERIMENTATION

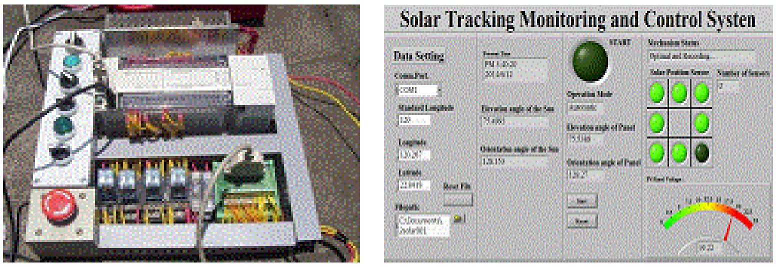
“Two-axis” means that the automatic system can be able to tracking sun follow two axes, Left-Right (orientation angle) and Up-Down (elevation angle) direction, simultaneously. The mechanism was constructed of aluminum frame and steel pedestal, and a PV panel, which with DC 21V rated voltage and 50W rated power, was mounted on the top of aluminum frame as shown in Figure 5. Figure 6 (a) shows Mitsubishi FX2N-48MR PLC and FX2N-4AD are connected as main PLC set for sending control signal and receiving voltage generated by the PV panel and Figure 6 (b) demonstrated a man-machine interface (MMI) of the monitoring/control system was developed to communicate with PLC-set via the

writing and reading command of Mitsubishi FX series PLCs. The monitoring/control system was developed by NI Lab VIEW 2010.



(a) (b)

Figure 5 :Automatic Two-Axis Solar Tracking Mechanism
(a) Front-View (b) Back-View



(a) (b)

Figure 6: (a) Control Panel Including FX2N PLC-Set and FX2N-4AD
(b) MMI of the Monitoring/Control System

Figure 7 (a) and (b) are demonstrated actual mechanical daily variation of the orientation and elevation angle, which compared with theoretical value calculated from Ref. [7]. The monitoring/control program will read the PLC status every 30 seconds, status data will also be updated on the MMI and recorded in database. The proposed tracking system could automatically trace position of sun, therefore, the output voltage of PV panel will maintain higher than the fix-angle system, which elevation angle is 23 degree, during daytime as shown in Figure 9. The voltage curves are averaged value of daily measurement record from May 19 to May 25 2014, including cloudy and sunny day

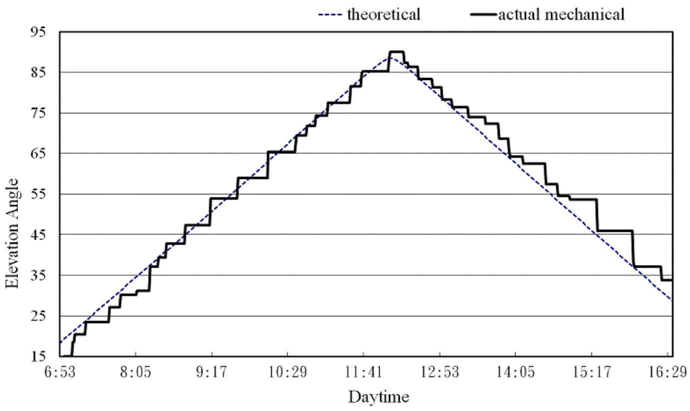


Figure 7: Daytime Variation of Elevation Angle

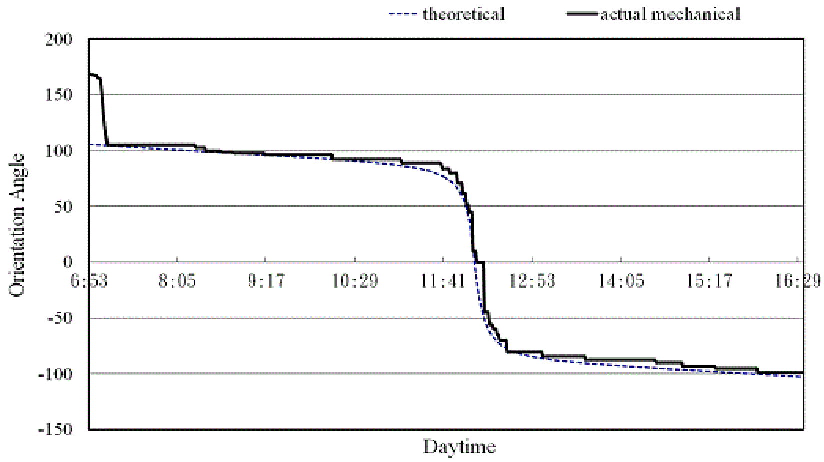


Figure 8: Daytime Variation of Orientation Angle

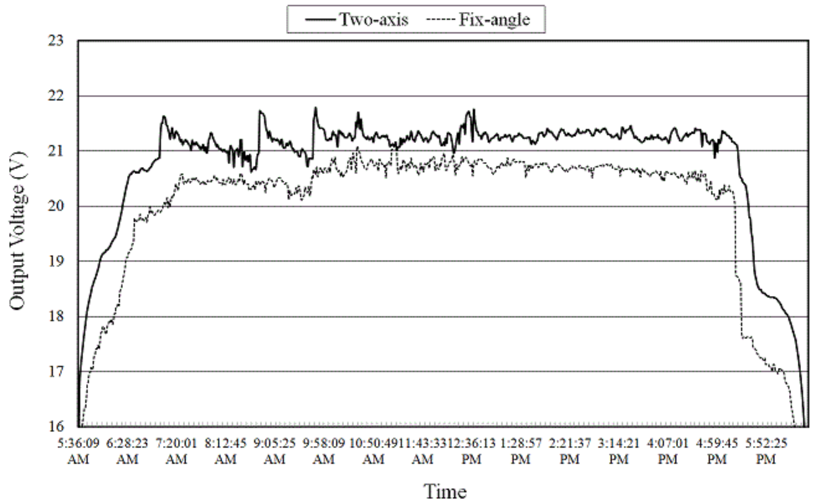


Figure 9: Comparison of Panel Voltage between Two-Axis Tracking System and Fix-Angle System

CONCLUSIONS

A dual-axis automatic solar tracking system and its Monitoring/Control system was proposed and implemented in this paper. It is low-cost, reliable and efficient. According to the experimental result, the proposed automatic solar tracking system has an overall energy increase of about 19%~28% more than the fix-angle PV system in sunny days, and about 9%~13% in cloudy days. Then, a MMI of the Monitoring/Control system was developed to pre-calculate the theoretical altitude angle and azimuth angle of the sun as coarse adjustment command for automatic mechanism, and storage all electrical and mechanical data into database.

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REFERENCES

1. Tadao Murata, “Petri Net: Properties, analysis, application,” Proceeding of IEEE, Vol. 77, No. 4, pp.541-580, 1989.
2. Richard Zurawski and Mengchi Zhou, “Petri Nets and industrial application: A tutorial,” IEEE Transactions on Industrial Electronics, Vol. 41, No. 6, 1994.
3. KurapatiVenkatesh, MengChu Zhou and Reggie Caudill, “Evaluating the Complexity of Petri Nets and Ladder Logic Diagrams for Sequence Controllers Design in Flexible Automation,” Proceeding of IEEE Symposium on Emerging Technologies and Factory Automation (ETFA '94), pp. 428–435, Nov. 6-10, 1994.
4. M. Uzam, A.H. Jones, and N. Ajlouni, ” Conversion of Petri Net Controllers for Manufacturing Systems into Ladder Logic Diagrams,” Proceeding of IEEE Symposium on Emerging Technologies and Factory Automation (ETFA '96), Vol. 2, pp. 649–655, Nov. 18-21, 1996.
5. Kurapati Venkatesh, Meng Chu Zhou and Reggie Caudill, “Comparing Ladder Logic Diagrams and Petri Nets for Sequence Controller Design through a Discrete Manufacturing System,” IEEE Transactions on Industrial Electronics, Vol. 41, No. 6, 1994.
6. Tsung-Yu Tsai, “Study the Difference of Solar Electricity Generation between the Fixed-Angle and Dual-Axis Tracker Systems,” Master Thesis, Southern Taiwan University of Sc. and Tech., Tainan City, Taiwan, R.O.C., 2006.
7. Viet Hung Pham, “Design and Investigation of a Two-Axis Automatic Solar Tracking System,” Master Thesis, Southern Taiwan University of Sc. and Tech., Tainan City, Taiwan, R.O.C., 2007.
8. Jong-Jinn Lay, “Development of a Sun Track Solar Energy System with Artificial Intelligence,” Master Thesis, National Sun Yat-Sen University, Kaohsiung City, Taiwan, R.O.C., 2007.
9. Ming-Huang Tsai, “Design and Implementation of a Wireless Monitoring/Control System for the Dual-axis Solar Tracking System,” Master Thesis, Kao Yuan University, Kaohsiung City, Taiwan, R.O.C., 2012.